

ESMD-RQ-0010 Preliminary (Rev. C) Effective Date: 14 Jan 2005

Exploration Systems Mission Directorate

National Aeronautics and Space Administration, Headquarters Washington DC 20546-0001

Exploration System of Systems Technical Requirements Document

Preliminary Version – Revision C 14 Jan 2005

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Document History Log

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Status (Baseline/Revision/ Cancelled)	Document Revision	Effective Date	Description
Preliminary		1 Sep 2004	
Preliminary (Rev. A)	ESMD Review	14 Oct 2004	
Preliminary (Rev. B)	NASA HQ Review	8 Nov 2004	
Preliminary (Rev. C)	CE&R Contractors and NASA Field Center Review	14 Jan 2005	

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1 Scope

1.1 Identification

This document is a summary of the NASA Exploration System of Systems Technical Requirements. When combined with the Exploration System of System Programmatic Requirement and Guidelines (ESMD-RQ-0021), they represent a first-level functional decomposition of the requirements expressed in *A Renewed Spirit of Discovery: The President's Vision for U.S. Space Exploration, January, 2004.* The Vision is expressed in requirements form in the *Level 0 Exploration Requirements for the National Aeronautics and Space Administration*, SA-0001, May 4, 2004.

The capabilities expressed in this document will evolve and expand over time, employing the Spiral Development Process to develop human-crewed, cargo, and robotic flight and ground systems to accomplish The Vision. Emphasis has been on the Crew Exploration Development and Test requirements (Exploration Spiral 1) and the Lunar Exploration requirements (Exploration Spirals 2&3), that provide long-duration human lunar exploration capability. Requirements development for Exploration Spiral 4 and beyond (human-Mars exploration) will be undertaken in the future. The controlling authority for this document is the Exploration Systems Mission Directorate (ESMD), Requirements Formulation Division, NASA Headquarters.

1.2 Document Overview

This document provides the Exploration System of Systems technical requirements that are then functionally decomposed and captured in individual Exploration Systems. The Exploration Systems hierarchy shown in Figure 1 explains the hierarchy of requirements documents that flow down from The Vision. The relationship of this document to other Exploration Systems requirements documents is shown in Figure 2.

Note: Where a requirement is expressed with "threshold and objective" values, it has been determined that performance above the threshold (minimum performance level) is of value to NASA as a desired "objective". Where no objective value is expressed, the value shown is the threshold requirement. Section 1 of this document contains background information with no direct requirements. Section 2 contains the applicable documents that Explorations Systems must comply with, as specified. Section 2 also contains reference documents that are for information only, that do not contain compliance requirements. Section 3 contains Exploration System of Systems requirements, beginning in Section 3.1. Section 4 contains a glossary of exploration terms, an acronym list, and a requirements taxonomy table.

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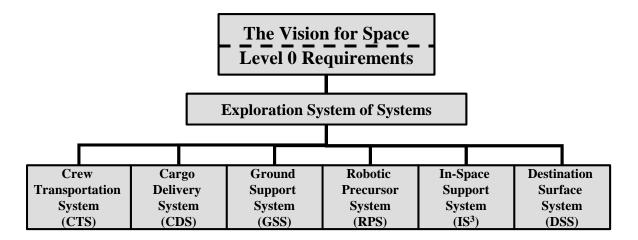


Figure 1: Exploration System of Systems Hierarchy

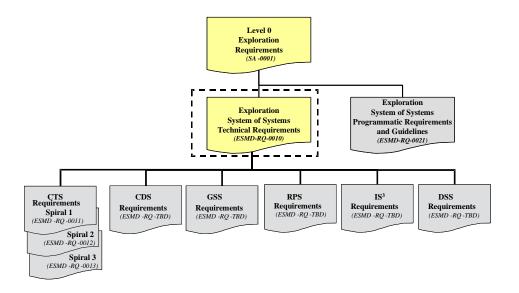


Figure 2: Exploration System Requirements Document Tree

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2 Documents

2.1 Applicable Documents

The following documents form a part of this requirements document to the extent specified herein. The version of the document applicable will be the latest revision at the time of contract award unless otherwise specified.

2.1.1 Government Documents

The Vision for Space Exploration (NP-2004-01-334-HQ)

Level 0 Exploration Requirements for the National Aeronautics and Space Administration (SA-0001)

NPR 7150, Software System Engineering Requirements

NPR 8705.2, Human Rating Requirements and Guidelines for Space Flight Systems

NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation

NPR 8715.3, NASA Safety Manual

NPR 8715.x, NASA Range Safety Program (in draft)

NASA-STD-8719.13, Software Safety NASA Technical Standards

2.1.2 Non-Government Documents

Reserved.

2.2 Reference Documents

The following documents specified herein are for reference only. Current document versions are referenced.

2.2.1 Government Documents

ESMD-RQ-0005, Lunar Architecture Focused Trade Study Final Report

ESMD-RQ-0006, Lunar Architecture Broad Trade Study Final Report

ESMD-RQ-0016, STTP-2 Meeting Minutes

ESMD-RQ-0018, Draft Polar Lunar Landing Site Rationale

ISBN 0-309-07031, Astronomy and Astrophysics in the New Millenium, National Academies of Science

NASA-STD-3000, Vol. I-IV, Man-Systems Integration Standards

NPR 1000.2, NASA Strategic Management Handbook

NPD 1050.1G, Authority to Enter into Space Act Agreements

NPD 1080.1A, NASA Science Policy

NPD 1200.1B, Internal Management Controls and Audit Liaison

NPD 1280.1, NASA Management System Policy

NPD 1360.2A, Initiation and Development of International Cooperation in Space and Aeronautics

Programs, NPD 1360.2A

NPR 1385.1, Public Appearances of NASA Astronauts and Other Personnel

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NPD 1387.1E, NASA Exhibits Program

NPR 1387.1, NASA Exhibits Program

NPD 1387.2F, Use, Control, and Loan of Lunar Samples for Public and Educational Purposes

NPD 1600.2C, NASA Security Policy

NPR 1620.1A, Security Procedural Requirements

NPR 1800.1, NASA Occupational Health Program Procedures

NPR 1800.2B, NASA Occupational Health Program

NPD 1810.2, NASA Occupational Medicine Program

NPD 1820.1B, NASA Environmental Health Program

NPD 2200.1, Management of NASA Scientific and Technical Information (STI)

NPR 2200.2A, Requirements for Documentation, Approval, and Distribution of NASA Scientific and Technical Information (STI)

NPD 2800.1, Managing Information Technology

NPR 2800.1, Managing Information Technology

NPD 2810.1C, NASA Information Security Policy

NPR 2810.1, Security of Information Technology

NPD 2820.1A, NASA Software Policies

NPD 3310.1A, Distinguishing between Contractor and Civil Service Functions

NPD 5101.32B, Procurement

NPR 5600.2B, Statement of Work (SOW); Guidance for Writing Work Statements

NPR 6000.1F, Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment, and Associated Components

NPD 7100.10D, Curation of Extraterrestrial Materials

NPD 7120.4B, Program/Project Management

NPR 7120.5B, NASA Program and Project Management Processes and Requirements Approval

Authorities for Facility Projects. NPD 7330.1F, Approval Authority for Facility Projects

NPD 7500.1A, Program and Project Logistics Policy

NPR 7500.1, NASA Technology Commercialization Process

NPR 8000.4, Risk Management Procedural Requirements

NPD 8020.7F Biological Contamination Control for Outbound and Inbound Planetary Spacecraft NPD 8020.7F

NPR 3020.12B, Planetary Protection Provisions for Robotic Extraterrestrial Missions

NPD 8610.7A, Launch Services Risk Mitigation Policy for NASA -Owned Or NASA -Sponsored Payloads

NPD 8610.23A, Technical Oversight of Expendable Launch Vehicle (ELV) Launch Services

NPD 8610.24A, Expendable Launch Vehicle (ELV) Launch Services Pre-launch Readiness Reviews

NPD 8700.1B, NASA Policy for Safety and Mission Success

NPD 8700.2A, NASA Policy for Safety and Mission Assurance (SMA) for Experimental Aerospace Vehicles (EAV)

NPD 8700.3A, Safety and Mission Assurance (SMA) Policy for NASA Spacecraft, Instruments, and Launch Services

NPR 8705.3, Safety and Mission Assurance (SMA) Requirements for Experimental Aerospace Vehicles (EAV)

NPR 8705.4, Risk Classification for NASA Payloads

NPR 8705.5, Probabilistic Risk Assessment (PRA) Procedures for NASA Programs and Projects

NPR 8715.1, NASA Safety and Health Handbook Occupational Safety and Health Programs

NPD 8720.1B, NASA Reliability and Maintainability (R&M) Program Policy

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NPD 8730.2B, NASA Parts Policy

NPD 8730.4A, Software Independent Verification and Validation (IV&V) Policy

NPR 8735.2, Management of Government Safety and Mission Assurance Surveillance Functions for

NASA Contracts

NPD 8820.2A, Design and Construction of Facilities

NPR 8820.2E, Facility Project Implementation Guide

NPD 8820.3, Facility Sustainable Design

NPD 8900.1F, Medical Operations Responsibilities in Support of Human Space Flight Programs

NPD 9501.1G, NASA Contractor Financial Management Reporting System

NPR 9501.2D, NASA Contractor Financial Management Reporting

NPD 9501.3A, Earned Value Management

NPR 9501.3, Earned Value Management Implementation on NASA Contracts

2.2.2 Non-Government Documents

Reserved.

3 System Requirements

The following text does provide, nor represent specific requirements, but is provided as context for the requirements that follow, beginning in section 3.1.

System Description

The Vision for Space Exploration requires NASA to implement an effective and exciting program of exploration and discovery. Sustained and affordable human and robotic missions will extend the human presence across the solar system. Innovative technologies, knowledge, and infrastructures will need to be developed. Over the next two decades, NASA plans to develop a number of new capabilities and systems that are critical to enabling safe and successful human and robotic missions. Vehicle elements to be fielded within this System of Systems will use a "spiral development" approach. In spiral development, the detailed end-state requirements are not known at program initiation. Requirements are refined through system development and demonstration, risk management and continuous user feedback. This approach will build on the experience gained in early Exploration Spirals, to provide flexibility in responding to scientific discoveries and to incorporate new technologies. Robotic Precursor Missions to the Moon and Mars will provide information necessary to conduct future human exploration (i.e., topography mapping, gravity maps, resource identification). In addition, Robotic Precursor Missions will serve as opportunities for advanced technology demonstrations.

Exploration Spiral 1/Crew Exploration Development and Test

Exploration Spiral 1 will establish the capability to test and checkout Crew Transportation System (CTS) elements in Low Earth Orbit (LEO) in preparation for future human exploration missions to the Moon. The capabilities necessary to satisfy the Spiral 1 objectives consist of a Crew Exploration Vehicle (CEV), a Crew Launch Vehicle (CLV), and ground support infrastructure. The CEV and CLV will safely transport the crew from the surface of the Earth to LEO, and return them to the Earth's surface at the completion of the mission. Demonstration of CEV and launch system performance are critical to enabling Spiral 1 objectives of safe transportation of the crew. Successive demonstrations of the CEV

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and launch system (including the ability to perform ascent and entry aborts) will begin with a series of risk reduction flight tests, and lead up to crewed CEV operational capability to support human exploration missions beyond LEO. The CEV must have a high degree of automated control to accomplish the early un-crewed test flights. Other CEV flights will test the automated rendezvous and docking systems, to develop the skills and techniques that will be needed for follow-on exploration missions. As exploration capabilities necessary for future spirals are developed, they will be tested with the CEV in the space environment to prepare for future exploration missions. Robotic exploration missions during Spiral 1 will investigate the lunar environment and provide the needed information to prepare for safe landings and human exploration of the lunar surface.

Spiral 1 Flight Hardware Functional Descriptions:

Crew Launch Vehicle:

Will provide the propulsive force necessary to launch the CEV into LEO.

Crew Exploration Vehicle:

Will provide the necessary crew habitation functions during ascent and entry, including mission aborts. Will also provide all maneuvering capability during orbit operations and entry (including aborts).

Robotic Precursor System:

Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

Ground Support System:

Ground based facilities and capabilities will provide the ability to plan, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

Exploration Spiral 2/Global Lunar Access for Human Exploration

Exploration Spiral 2 will establish the capability to conduct human exploration missions to any location on the surface of the Moon without pre-positioned surface infrastructure. This Spiral 2 capability will likely be utilized to conduct human exploration of potential lunar base sites prior to the delivery of habitats and surface power systems (Destination Surface Systems). This capability could also be utilized to place humans at the lunar base camp location for habitat and surface power systems final assembly tasks. Once the lunar base is established, this Spiral 2 capability could be utilized to explore locations which are not accessible via surface mobility assets. The systems necessary to satisfy Spiral 2 objectives consist of those developed in Exploration Spiral 1, or derivatives of those capabilities, plus Earth Departure Stage(s) (EDS) necessary to transport elements to the lunar vicinity as well as the Lunar Surface Access Module (LSAM) that will provide the capability for the crew to access the lunar surface. The Cargo Delivery System will deliver un-crewed elements of the Crew Transportation System into LEO and/or lunar orbit (e.g., EDS). Spiral 2 will include successive flight tests to demonstrate the flight characteristics of the CEV, EDS, and LSAM to gain knowledge of how the systems perform at greater distances from Earth and increasing levels of autonomy. Focused robotic precursor technology demonstration missions to Mars are also anticipated within this Spiral.

Spiral 2 Flight Hardware Functional Descriptions:

Crew Launch Vehicle:

Will provide the necessary propulsive force to launch the CEV and other mission elements into LEO.

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Crew Exploration Vehicle:

Will provide the necessary crew habitation functions from launch to lunar orbit and return to the Earth surface, including aborts during Earth ascent. The CEV will also provide the necessary propulsive accelerations to return the mission crew from lunar orbit, independent of orbital alignment, for direct entry at Earth. The CEV will rendezvous and dock with other mission elements, such as the EDS and LSAM, in both LEO and lunar orbit. In addition, the CEV will operate un-crewed in lunar orbit while the crew is on the surface of the Moon.

Earth Departure Stage(s):

Will provide the necessary propulsive accelerations needed to transfer the various flight elements (CEV and LSAM) from LEO to lunar orbit, and provide the deceleration for lunar orbit insertion.

Lunar Surface Access Module:

Will provide the necessary crew habitation and transportation functions from lunar orbit to the lunar surface and during return to lunar orbit; will provide crew habitation during lunar surface operations. In addition, the LSAM will provide the capability for the crew to conduct science and perform routine Extra-Vehicular Activity (EVA) on the surface of the Moon.

Cargo Delivery System:

Will deliver un-crewed elements of the CTS into LEO and/or lunar orbit. CDS elements include the Cargo Launch Vehicle and the EDS.

Robotic Precursor System:

Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

Ground Support System:

Ground based facilities and capabilities will provide the ability to plan, test, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

Exploration Spiral 3/Lunar Base and Mars Testbed

Exploration Spiral 3 will establish the capability to conduct routine human long-duration missions at a lunar base to test out technologies and operational techniques for expanding the human presence to Mars and beyond. Missions in Spiral 3 will extend up to several months in duration at the lunar poles or equatorial region in order to serve as an operational analog of future Mars missions. Spiral 3 will require the development and deployment of habitats and surface power systems. These Destination Surface Systems (DSS) will be delivered to a selected location in the polar or equatorial region by the Cargo Delivery System (CDS). The number, type, and sequencing of these CDS missions have not yet been specifically defined. Once the surface systems are in place, successively longer missions will be conducted to increase the understanding of system technical performance (including health and human systems), and to provide increasing levels of operational autonomy capabilities that will be necessary for future human Mars exploration missions. The Spiral 2 capability for global access is retained in Spiral 3, and will allow exploration missions to locations not accessible from the base camp via surface mobility assets.

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Spiral 3 Flight Hardware Functional Descriptions:

Crew Launch Vehicle:

Will provide the necessary propulsive force to launch the CEV and other mission elements into LEO.

Crew Exploration Vehicle:

Will provide the necessary crew habitation and health maintenance functions from launch to lunar orbit and return to the Earth surface, including aborts during Earth ascent. The CEV also will provide the necessary propulsive accelerations to return the mission crew from lunar orbit, independent of orbital alignment, for direct entry at Earth. The CEV will rendezvous and dock with other mission elements, such as the EDS and LSAM, in both LEO and lunar orbit. In addition, the CEV will operate un-crewed in lunar orbit while the crew is on the surface of the Moon.

Earth Departure Stage(s):

Will provide the necessary propulsive accelerations needed to transfer the various flight elements (CEV, LSAM, and cargo vehicles) from LEO to lunar orbit and provide the deceleration for lunar orbit insertion.

Lunar Surface Access Module:

Will provide the necessary crew habitation and transportation functions from lunar orbit to the lunar surface, and return to lunar orbit. In addition, the LSAM will provide the capability for the crew to perform EVA on the surface of the Moon in order to transition to the surface elements for the long duration missions. The LSAM will remain on the surface of the Moon during the long-duration surface missions.

Cargo Delivery System:

Will deliver un-crewed elements of the Crew Transportation System into Low Earth Orbit and/or lunar orbit. CDS elements include the Cargo Launch Vehicle and the EDS. The CDS will also deliver elements of the DSS from a low lunar orbit to the desired location on the surface of the Moon. The CDS elements have not been completely identified at this time, but should include a Cargo Launch Vehicle, Cargo Destination Landing System, and the EDS.

Destination Surface System:

Will provide crew support capabilities to enable long-duration surface missions. The elements that comprise this system have not been completely defined at this point, but will provide functionality including habitation, communication, power, extended range mobility, enhanced science capabilities, etc. DSS will provide the capability for the crew to conduct long-duration surface science, and perform EVA on the surface of the Moon.

Robotic Precursor System:

Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

Ground Support System:

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Ground based facilities and capabilities will provide the ability to plan, test, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

3.1 Mission Definition

ESS0040 The Exploration System of Systems shall conduct human exploration of the Moon using established safety requirements and processes for development and operations.

Rationale: Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

ESS0050 The Exploration System of Systems shall conduct human exploration of Mars using established safety requirements and processes for development and operations.

Rationale: Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

ESS0060 The Exploration System of Systems shall conduct human exploration to other destinations, as identified in the Exploration Spirals, using established safety requirements and processes for development and operations.

Rationale: Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

ESS0010 The Exploration System of Systems shall conduct robotic exploration of the Moon using established safety requirements and processes for development and operations.

Rationale: Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

ESS0020 The Exploration System of Systems shall conduct robotic exploration of Mars using established safety requirements and processes for development and operations.

Rationale: Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

ESS0030 The Exploration System of Systems shall conduct robotic exploration of other solar system destinations, as identified in Exploration spirals, using established safety requirements and processes for development and operations.

Rationale: Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

ESS0080 The Exploration System of Systems shall explore Jupiter's moons, asteroids, and other bodies to search for evidence of life, to understand the history of the solar system, and to search for resources.

Rationale: Direct flow-down from Level 1 Exploration Objective (1.3), contained in Level 0 Requirements document. Exploration of Europa was ranked as the top priority of the Decadal Survey. These programs may spawn technology breakthroughs that facilitate human exploration of the Moon and Mars.

Reference: ISBN 0-309-07031, "Astronomy and Astrophysics in the New Millennium", National Academies of Science.

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ESS0070 The Exploration System of Systems shall demonstrate power generation, propulsion, life support, and other key capabilities required to support human and robotic exploration of Mars and other destinations.

Rationale: Direct flow-down from Level 1 Exploration Objective (1), contained in the Level 0 Requirements document. New technologies and capabilities such as closed loop life support, power generation (solar or non-solar) and propulsion advances are required for human exploration of Mars.

ESS0680 The Exploration System of Systems shall provide the infrastructure including range accommodations, facilities (planning, training, and operations), platforms, communications systems, transportation systems, outpost accommodations, equipment, and other command, communication, control and computer resources to support Exploration missions.

Rationale: This requirement is flowed down from the Level 0 Exploration Requirements (1.1): "NASA shall develop the innovative technologies, knowledge, capabilities, and infrastructures to support human and robotic exploration". The System of Systems infrastructure will be vital to successful execution of Exploration missions.

ESS0570 The Exploration System of Systems shall process, integrate, test, launch, operate, and recover the crew and Exploration flight elements (as appropriate) in support of Exploration missions.

Rationale: NASA must provide an aggregate infrastructure capability to implement The Vision for Space. This infrastructure must process flight hardware from completion of development through launch. This infrastructure must also provide for ground control functions (including human systems monitoring) during Exploration missions, and recover the CEV and crew at mission completion.

ESS0670 The Exploration System of Systems shall establish "Design for Minimum Risk" criteria for components/systems which do not meet the applicable failure tolerance requirements to include the following elements:

- (a) The Program must evaluate the impact of meeting the related failure tolerance requirement, and find the failure tolerant design to be either; impractical (impacts to cost, schedule, or performance that would cause program cancellation or prevent mission execution), or to have a negative impact on overall system reliability, or to have negligible benefit, as based on a probabilistic risk assessment accepted by the appropriate Independent Technical Authority (ITA).
- (b) The component/system hazards and critical failure modes must be analyzed to determine the full affect on the System hazards and risks.
- (c) The component/system hazards and failure modes must be accepted by the Program and appropriate ITA with adequate retention rationale.
- (d) The specific component/system "Design for Minimum Risk Criteria" must be formally accepted, documented and implemented by the Program with concurrence from the appropriate ITA.
- (e) When "Designing for Minimum Risk" in place of the two failure tolerant requirement, single failure tolerance to catastrophic hazards must be utilized unless the conditions of (a) above also apply to the single failure tolerant design.

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Rationale: This requirement details the process that is required to allow "Design for Minimum Risk" as an alternative for components that by the nature of their function cannot be made failure tolerant. "Design for Minimum Risk" is an accepted engineering practice using control through specified factors of safety, factors of material properties or other properties inherent to the design of the part, component, subassembly, or assembly to ensure system safety. Examples of "Design for Minimum Risk" areas are structures safety (i.e. structural factor of safety of 1.4), pressure vessels, pressurized lines and fittings, and pyrotechnic devices. These components are certified safe based upon their inherent properties to withstand their required usage as verified by analysis, qualification and acceptance testing. Although the technical criteria for "Design for Minimum Risk" are documented in several NASA standards, the process needed to ensure full implementation and compliance must be documented. This requirement details the process that must be followed by all NASA Exploration programs and its contractors to ensure that the crew and system are not jeopardized by insufficient application of fault tolerance requirements.

(The Human Rating Requirements Document Working Group is currently working on a detailed definition and process of "Design for Minimum Risk" for NPR 8705.2, "Human Rating Requirements for Space Systems". When the revised NPR is approved, this requirement will have to be readdressed to ensure that it is consistent with the revised NPR.)

ESS0690 The Exploration System of Systems shall meet the failure tolerance requirements during operations in space without the use of crew Extra-Vehicular Activity (EVA).

Rationale: Using EVA as a leg of failure tolerance puts the crew at additional risk. The system design should be robust and reliable enough that EVAs would only be needed to recover from failures that are impractical to adequately protect through redundancy or other means.

ESS0700 The Exploration System of Systems shall execute nominal assembly operations in flight (e.g., docking or mating of two or more elements) without the use of crew EVA.

Rationale: This requirement will impact the design of the System of Systems when operations call for flight element assembly or integration in Low Earth Orbit or lunar orbit. As demonstrated in the assembly of the space station, allowing the program to use EVA for this assembly would result in higher training costs, additional risk to the crew, and extended mission durations in Low Earth Orbit prior to departure for the destination. When docking or mating of elements is required for return to Earth, allowing EVA for the nominal operation would increase risk to the crew, complicate the return scenario, and extend the amount of time required to return the crew to Earth, which is not acceptable for contingency returns.

ESS0090 The Exploration System of Systems shall provide information, data, and scientific opportunities to support educational outreach activities and public awareness campaigns.

Rationale: The Level 0 Requirement (6) states that "NASA shall identify and implement opportunities within missions for the specific purposes of inspiring the Nation." This requirement is a flow-down to the Exploration System of Systems to provide for all the data (real time and non-real time) and information necessary to inform the general public and inspire a new generation of scientists, mathematicians, and engineers in our educational institutions. This requirement is written to serve as a parent requirement to technical communication capabilities necessary to provide video, voice and data to the general public via print, broadcast and electronic media.

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3.2 Spiral Definition

3.2.1 Exploration Spiral 1 (S1)

ESS0100 The Exploration System of Systems shall demonstrate human spaceflight capabilities in Low Earth Orbit (LEO) to prepare for future exploration missions.

Rationale: Successive demonstration of capabilities necessary to expand exploration to further destinations is a fundamental strategy for spiral development. Capabilities and infrastructure developed in early spirals are utilized to test and emplace systems needed for subsequent spirals. In addition, early spirals will serve as the building blocks for subsequent spirals, capitalizing on new technologies and operational concepts gained from previous missions. Successful demonstration of human spaceflight in LEO is a necessary element in the progression to human exploration beyond LEO.

ESS0110 The Exploration System of Systems shall conduct Robotic Precursor Missions to lunar orbit and the lunar surface to prepare for future human exploration.

Rationale: Further definition of Spiral 1. Robotic Precursor Missions will provide information necessary to conduct future human exploration (i.e., topography mapping, gravity maps, and resource identification). In addition, Robotic Precursor Missions will serve as opportunities for demonstration of advanced technologies.

3.2.2 Exploration Spiral 2 (S2)

ESS0120 The Exploration System of Systems shall demonstrate the capabilities necessary to prepare for long-duration human exploration of the Moon.

Rationale: This requirement is a flow-down of Level 0 Exploration Requirement (1.3) "NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations." Spiral 2 is primarily a preparatory step toward long-duration exploration on the moon, which will, in turn, be used to prepare for Mars exploration.

ESS0130 The Exploration System of Systems shall conduct human lunar exploration missions to further science.

Rationale: This requirement is a flow- down of Level 0 Exploration Requirement (1.3) "NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations." This requirement captures the science objective of exploration.

ESS0150 The Exploration System of Systems shall conduct human exploration missions with a surface duration (threshold) of 4 days (**TBR-2**), and an objective of 7 **TBD** days (**TBD-78**) to any designated location on the lunar surface (global lunar access).

Rationale: This requirement establishes the fundamental capability to send humans to any location on the moon and return them to Earth. This capability will be used initially for extended duration exploration at potential sites of a lunar base camp and for any final assembly tasks prior to the base camp

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initial operating capability (IOC). Once long duration missions at the lunar base are started in Spiral 3, this Spiral 2 capability will be used for crew transport to/from the lunar base and for missions to locations on the lunar surface that are not accessible via surface mobility from the lunar base. Analysis indicates that 4-7 day surface duration is bounded by the lander capability and, for mid latitude mission, the return plane change requirements. Also, this requirement does not imply the ability to go anywhere on the Moon at any time. Thermal constraints on a system designed for polar missions may restrict when a given non-polar mission can be conducted. However, the capability for humans to explore any area of exploration interest on the lunar surface is provided in this Spiral.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results."

TBD/TBR Closure: This capability is driven primarily by anytime return and will be established during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

ESS0160 The Exploration System of Systems shall conduct human exploration on the lunar surface with a threshold of 4 crew members, and an objective of 6 crew members (**TBR-15**).

Rationale: A 4 person crew is the minimum number required to demonstrate operations concepts for exploring more distant destinations such as Mars. A 4 person crew (threshold) allows two EVA teams (2 crew per team) to operate simultaneously or in series while providing the capability for operational assistance from the non-EVA crew. A 6 person crew (objective) represents the most likely Mars exploration crew size, based on previous studies. However, since human rated launch capability is likely to be a limiting factor on CEV capability, 6 person crew size is carried as an objective only. Lower level requirements for each element will specify the capability to operate with fewer than 4 or 6 crew. Human exploration includes the use of robotic elements as part of the system.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

TBR-15 Closure: Further surface scenario assessments are required during the CE&R study phase. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

ESS0170 The Exploration System of Systems shall provide a minimum flight rate capability of 1 human exploration mission to the lunar surface per year (**TBR-6**).

Rationale: This requirement is a flow-down of Level 0 Requirements (1) calling for "a safe, sustained, and affordable robotic and human program."

The Exploration System of Systems must be designed to support and be available for a minimum mission frequency in order to provide a sustainable Exploration program. Spiral and mission objectives must be achieved efficiently in order to achieve the challenging Level 0 milestones set for human exploration of the Moon, and ultimately Mars. A minimum flight rate should also be sufficient to support efforts to maintain flight and ground crew proficiency.

TBR-6 Closure: Additional data will be developed during the CE&R studies. This issue will be resolved

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no later than 90 days prior to the CEV System Requirements Review.

ESS0190 The Exploration System of Systems shall provide a minimum of 1 lunar mission opportunity per month (**TBR-8**).

Rationale: A mission opportunity is the time window for departure from the Earth vicinity to the Moon. Although budgets and operational factors will drive the frequency of missions, it is important that the program not be restricted to a small number of mission opportunities per year.

This requirement sets the minimum rate for mission opportunities. Specific architecture choices could severely limit mission opportunities and therefore would be eliminated by this requirement. This requirement does not imply that the ESS will be able to actually execute a mission every month, nor does it imply that all launches to support a single mission must occur within a one month period.

Frequent mission opportunities are important, to allow sufficient recovery options, should a given mission opportunity be missed.

TBR Closure: Additional data to support budget and funding profiles will be developed during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review

ESS0200 The Exploration System of Systems shall conduct robotic missions to lunar orbit, lunar vicinity, and the lunar surface in support of human exploration.

Rationale: Robotic missions to the Moon are likely to continue in Spiral 2. With the capability to deliver humans to any site of interest on the moon, robotic missions can identify specific areas for human exploration, and integrated robotic and human exploration missions may be undertaken.

ESS0210 The Exploration System of Systems shall conduct Robotic Precursor Missions to Martian orbit, Martian vicinity, and the surface of Mars to prepare for future human exploration.

Rationale: Further definition of the Spiral. Direct flow-down from Level 0 requirements.

ESS0220 The Exploration System of Systems shall conduct Robotic Precursor Missions to Martian Orbit, Martian vicinity and the surface of Mars to perform science.

Rationale: Further definition of the Spiral. Direct flow-down from Level 0 requirements.

3.2.3 Exploration Spiral 3 (S3)

ESS0230 The Exploration System of Systems shall conduct human lunar exploration missions to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources, to support sustained human space exploration to Mars and other destinations.

Rationale: This requirement is a flow-down of Level 0 Exploration Requirement (1.3) "NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations." Demonstration of key systems, technologies,

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and operational approaches that are applicable for Mars exploration are Spiral 3 primary objectives.

ESS0240 The Exploration System of Systems shall conduct human lunar exploration missions to further science.

Rationale: This requirement is a flow-down of Level 0 Exploration Requirement (1.3) "NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations." This requirement captures the science objective of exploration.

ESS0260 The Exploration System of Systems shall conduct long-duration human exploration missions with a surface duration (threshold) of 42 days (**TBR-3**), and an objective of 98 days (**TBR-4**)) to any designated location in the polar or equatorial regions (**TBR-17**) of the Moon.

Rationale: Long-duration missions are required to test operational concepts and systems for future Mars exploration. These long duration missions will require establishing a lunar base with surface infrastructure such as habitats, surface power systems, etc. The location for this lunar base will depend on the results of the early robotic precursor missions in Spiral 1, with the south pole and the equator as the most promising regions. Surface durations for opposition class Mars missions range from 30-90 days depending on the mission opportunity and propulsion technology employed. Lunar surface testing of operational concepts involves mission planning for exploration activities over a similar period. The daynight cycle on Mars is similar to Earth. However, on the Moon, 14 days of light are followed by 14 days of dark. The threshold duration allows for 2 day cycles and 1 night cycle. The objective duration is similar to a typical Mars short stay mission and allows for 4 day cycles and 3 night cycles. The primary objectives are demonstration of technologies and operational concepts, and science.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

TBR Closure: Surface stay durations will be defined once the launch strategy is defined and during further assessments of the surface element design activities. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

ESS0280 The Exploration System of Systems shall provide a minimum flight rate capability of 1 human exploration mission to the lunar surface per year (**TBR-9**).

Rationale: This requirement is a flow-down of Level 0 Requirements (1) calling for "a safe, sustained, and affordable robotic and human program."

The Exploration System of Systems must be designed to support and be available for a minimum mission frequency in order to provide a sustainable Exploration program. Spiral and mission objectives must be achieved efficiently in order to achieve the challenging Level 0 milestones set for human exploration of the Moon, and ultimately Mars. A minimum flight rate should also be sufficient to support efforts to maintain flight and ground crew proficiency.

TBR-9 Closure: Additional data to support budget and funding profiles will be developed during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements

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Review.

ESS0285 The Exploration System of Systems shall have the capability to deliver cargo to the lunar surface.

Rationale: This requirement expresses the need for delivery of uncrewed payloads to the lunar surface. This capability will be needed to pre-deploy Destination Surface System assets (e.g., Habitation Module, Surface Power System) for use during human lunar exploration missions. This requirement will serve as a parent for the Cargo Delivery System.

ESS0300 The Exploration System of Systems shall provide a minimum of 1 lunar mission opportunity per month (**TBR-11**).

Rationale: Although budgets and operational factors will determine the actual frequency of missions, it is important that the program not be restricted to a small number of mission opportunities. This requirement sets the minimum rate for mission opportunities. Specific architecture choices could severely limit mission opportunities and therefore would be eliminated by this requirement.

TBR-11 Closure: Additional data to support budget and funding profiles will be developed during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

ESS0310 The Exploration System of Systems shall conduct robotic missions to lunar orbit, lunar vicinity, and the lunar surface in support of human exploration.

Rationale: Robotic missions to the Moon are likely to continue in Spiral 3. With the capability to deliver humans to any site of interest on the moon, robotic missions can identify specific areas for human exploration, and integrated robotic and human exploration missions may be undertaken.

ESS0320 The Exploration System of Systems shall conduct Robotic Precursor Missions to Martian orbit, Martian vicinity, and the surface of Mars to prepare for future human exploration.

Rationale: Further definition of the Spiral. Direct flow-down from Level 0 requirements.

ESS0330 The Exploration System of Systems shall conduct Robotic Precursor Missions to Martian orbit, Martian vicinity, and the surface of Mars to perform science.

Rationale: Further definition of the Spiral. Direct flow-down from level 0 requirements.

3.3 NASA Procedural Requirements (NPRs)

ESS0340 The Human elements of the Exploration System of Systems shall comply with NPR 8705.2, Human-Rating Requirements and Guidelines for Space Flight Systems

Rationale: NPRs are agency level requirements and not at the discretion of the Directorate. In order to fly humans in space, each element of the System of Systems that interfaces with the crew must be certified as human rated. NPR 8705.2 delineates the requirements and process for obtaining that certification and is applicable to those elements that interact with the crew.

The current version is NPR 8705.2 with Change 2 dated 6/25/04. The document is currently under review

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and a new approved version is expected prior to release of the CEV RFP.

ESS0350 The Exploration System of Systems shall comply with NPR 8715.3, NASA Safety Manual.

Rationale: NPRs are agency level requirements and not at the discretion of the Directorate. This document contains the requirements and procedures for NASA Safety Programs to minimize risk to personnel and equipment.

ESS0370 The Exploration System of Systems shall comply with NPR 7150, NASA Software Engineering Requirements.

Rationale: NPRs are agency level requirements and not at the discretion of the Directorate. Specific version and dates shall be identified in the spiral requirements.

ESS0380 The Exploration System of Systems shall comply with NPR 8715.x (**TBD-65**), NASA Range Safety Program.

Rationale: NPRs are agency level requirements and not at the discretion of the Directorate. Space systems launched from U.S. ranges are required to comply with Air Force Range Requirements as tailored for the system. The Range Safety NPR will contain the NASA tailored requirements to launch on U.S. Ranges.

TBD Closure: This NPR is currently in the NODIS review cycle; approval is expected in early 2005.

ESS0650 The Exploration System of Systems shall dispose of expendable flight elements at end of life in accordance with NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation.

Rationale: Disposal of any flight hardware that may generate orbital debris in Earth orbit, or may reenter the Earth's atmosphere are governed by this NPD. Abort towers, ascent stages, and earth departure stages are examples of potential flight hardware covered by this NPD.

ESS0360 The Exploration System of Systems shall comply with NASA-STD-8719.13, Software Safety Standard, for all Safety-Critical Software.

Rationale: Software is a critical component of all complex space systems. Safety Critical Software (as defined in NASA-STD-8719.13) must be developed and tested to ensure the safety of the crew. The definition of Safety Critical Software is also contained in the requirements glossary. Although 8719.13 is a standards document, it contains specific software requirements.

4 Glossary and Acronyms

4.1 Acronyms and Abbreviations

CDS Cargo Delivery System

CE&R Concept Exploration and Refinement

CEV Crew Exploration Vehicle

CEVLS Crew Exploration Vehicle Launch Segment

CLV Crew Launch Vehicle

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CG	Center of Gravity
CU	Center of Gravity

Crew Transportation System CTS **Destination Surface System** DSS **EDS** Earth Departure Stage

Entry Interface ΕI

ECLSS Environmental Control/Life Support System **Exploration Systems Mission Directorate ESMD**

ESS Exploration System of Systems

Extra-Vehicular Activity **EVA**

Guidance, Navigation, and Control GN&C

GSS **Ground Support System**

IRD Interface Requirements Document **Integrated Logistics Support** ILS IS^3 In-Space Support System **Independent Technical Authority** ITA

Jupiter Icy Moon Orbiter JIMO

Low Earth Orbit LEO LRL Lunar Robotic Lander LRO Lunar Robotic Orbiter

LSAM Lunar Surface Access Module

NEDD Natural Environments Definition for Design **NODIS** NASA Online Directives Information System

NP **NASA Publication**

NPD NASA Policy Documents

NPR NASA Procedural Requirement (Document)

Operations Advisory Group OAG

Office of Safety and Mission Assurance OSMA

OSP Orbital Space Plane

Probabilistic Risk Assessment **PRA**

RFP Request for Proposals **RPS** Robotic Precursor System System Requirements Review SRR

Standard (Document) STD

Strategy to Task to Technology Process (or Panel) **STTP**

TBD To Be Determined TBR To Be Resolved

TPS Thermal Protection System

4.2 Glossary

Early mission termination due to failure(s) that preclude mission continuation. Return to Earth of the crew is accomplished inside the spacecraft designed for Earth return and landing (see Abort to Earth, Abort to Orbit).

Early mission termination, with direct return to the Earth's surface as the immediate **Abort to Earth** objective.

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Abort to Orbit An early mission termination that has an immediate objective of placing a crewed flight system in Earth (or destination vicinity) orbit, prior to return to the Earth's surface.

Annunciate To provide a visual, tactile or audible indication.

Ascent The function of liftoff from the Earth (or mission destination) surface, to spacecraft insertion into Earth/destination orbit.

Automated control Automatic, as opposed to human operation or control of a process, equipment or a system; or the techniques and equipment used to achieve this. Automation is the control or execution of actions with no human interaction. Automated control does not exclude the capability for manual intervention / commanding, but manual intervention / commanding is explicitly not required to accomplish the function.

Autonomous operations Defined as a flight vehicle operating independent of external commands or control (i.e., commands from mission control on Earth). Autonomous operations can be fully automated or require some degree of manual commanding/intervention by the onboard crew. Autonomous operations that do not require onboard crew involvement are, by definition, automated; therefore, the term "autonomous operations" used in the requirements assumes onboard crew involvement in the operations.

Berthing A method of mating two or more Exploration elements in space. During a berthing operation, the two elements are mechanically connected prior to the structural capture and final mating (i.e., one element grapples the other with a robotic arm). One element controls the trajectory and attitude of the other element for the contact and capture. Final mating is generally performed by the berthing mechanism (also see docking).

Cargo Delivery System (CDS) The CDS encompasses the capability to deliver all non-CEV flight elements needed to accomplish human exploration objectives. At such time as CDS elements dock with the CEV, they are part of a human crew occupied system, and are considered part of the CTS.

Cargo Launch Vehicle The Cargo Launch Vehicle is an element of the Cargo Delivery System. The Cargo Launch Vehicle will perform the ascent function for non-crewed elements of the CTS (EDS, LSAM), into an Earth Orbit. Since the Cargo Launch Vehicle will not carry human crew, it will not require Human-Rating.

Catastrophic Hazard A condition that may cause death or permanently disabling injury, major system or facility destruction on the ground, or major systems or vehicle destruction during the mission. (From NPR 8715.3 Safety Manual)

Consumables Resources that are consumed in the course of conducting a given mission. Includes propellant, power, habitability items (e.g., gaseous oxygen), and crew supplies.

Contingency EVA Capability An EVA capability provided to deal with critical failures or circumstances, which are not adequately protected by redundancy or other means.

Crew Exploration Vehicle (CEV) The CEV provides crew habitation and Earth reentry capability for all Exploration Spirals.

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Crew Exploration Vehicle Launch Segment (CEVLS) The CEVLS consists of a Crew Exploration Vehicle (CEV), a Crew Launch Vehicle (CLV), and all the dedicated ground support infrastructure necessary to launch the CEV to Earth orbit.

Crew Launch Vehicle (CLV) The CLV is an element of the CTS. The CLV will be human-rated, and will deliver the CEV into a mission-specific Earth Ascent Target Orbit.

Crew Member Human onboard the spacecraft or space system during a mission.

Crew Transportation System (CTS) The CTS encompasses the flight elements needed to deliver a human crew from Earth to a mission destination, and return the crew safely to Earth. The CTS must interact with the Ground Support System (GSS) during all Spirals; current architectures require delivery of the EDS and LSAM to Earth orbit through use of the CDS.

Critical Hazard A condition that may cause a severe injury or occupational illness, loss of mission, or major property damage to facilities, systems, or flight hardware.

Day Defined as an Earth day of 24 hours.

Destination Surface System (DSS) The DSS encompasses all elements (exclusive of the surface lander that transports the crew to the destination surface) necessary to enable a long-duration human exploration mission. Examples of DSS elements include a long-duration habitation module, surface power capability, and surface transportation systems. DSS elements will be delivered to the destination surface via the CDS. It is likely that these assets will be pre-deployed in advance of the crew that will utilize them to execute a given Exploration mission.

Destination Surface to Destination Vicinity Phase Starts with the initiation of the ascent (T0) from the destination surface. Representative mission activities include: ascent, abort, and orbit insertion or libration capture. Phase ends after successful destination vicinity insertion/capture.

Destination Vicinity Operations Phase (A) Starts at the successful insertion/capture at the destination vicinity. Representative mission activities include: loiter and phasing, vehicle and system checkout, crew-cargo transfers, undocking and separation. Phase ends at the successful separation of surface lander system for descent burn.

Destination Vicinity Operations Phase (B) Starts after the successful destination orbit insertion or libration point capture, following ascent from destination surface. Representative mission activities include: phasing, vehicle-system checkout, crew-cargo transfer, undocking and separation maneuver, element disposal and/or safing. Phase ends at the completion of the Trans-Earth Injection burn.

Destination Vicinity to Earth Phase Begins with completion of Trans-Earth Injection burn and includes mid-course corrections, cruise to Earth vicinity, element separation and element disposal. Ends with arrival at Earth entry interface or insertion to Earth orbit.

Destination Vicinity to Destination Surface Phase Starts at the initiation of the descent burn from destination vicinity (destination deorbit burn or libration departure burn to destination). Representative

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mission activities include: descent to destination surface, descent aborts, landing, propulsion system shutdown and safing. For libration architectures, additional activities include orbit capture, phasing, and de-orbit maneuvers. Phase ends when the vehicle has completed all landing activities on the destination surface, including propulsion system shutdown and safing.

Docking A method of mating two or more Exploration elements in space. In a docking operation, the structural mechanisms are brought into contact and captured through independent control of the two vehicles' flight path and attitude. Final mating is generally accomplished by the docking mechanism (also see Berthing).

Earth Ascent Target Orbit The planned orbit, at conclusion of the ascent function.

Earth Departure Stage (EDS) EDS will be used to provide the propulsive force needed to transfer the various flight elements to destination phasing orbits (including the CEV and LSAM).

Earth-Moon Transit Transit of a spacecraft between Earth vicinity and Lunar vicinity in either direction.

Earth Orbit Operations Phase (A) Starts with completion of Earth orbit insertion. Representative activities include: phasing, rendezvous, docking and loiter. Ends with completion of a burn to leave Earth orbit (i.e., Trans-Lunar Injection burn or de-orbit burn).

Earth Orbit to Destination Vicinity Phase Starts after completion of vehicle injection burn (i.e., Trans-Lunar Injection) and includes mid-course corrections, element separation/disposal, and cruise to destination vicinity. Ends with successful insertion/capture at destination vicinity.

Earth to Orbit Phase Starts with liftoff. Representative activities include liftoff through ascent to orbit, ascent crew escape/abort and re-entry/descent during aborts, disposal of elements. Ends with insertion to a stable, 24 hour Earth orbit or return to Earth (in the event of an abort).

Earth Re-entry Phase Begins with arrival at Earth entry interface (for direct re-entry) or completion of Earth orbit injection (for aerocapture), continues through the de-orbit burn and ends with landing on the Earth's surface. Encompasses activities necessary to successfully execute direct-to-Earth aborts during ascent and direct entry return from beyond Earth orbit.

Earth Reference Orbit The orbit designated for assembly of Exploration System elements prior to departure for exploration destinations, defined by the following parameters: Inclination: 28.5-29.0 degrees; Launch Azimuth: 90+/- 5 degrees; Altitude: 307 km - 407 km.

Entry footprint Region on Earth's surface defined by the boundaries of the Earth entry corridor for a given vehicle.

Equatorial Region of the Moon Defined as the area between 0-20 degrees lunar latitude (threshold), with an objective of 0-30 degrees (**TBR**).

Escape Early mission termination that requires emergency egress of the Crew from the failing spacecraft, possibly using an escape system (e.g., extraction, ejection, escape pod).

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Exploration Spiral 1 (Crew Exploration Development and Test) Encompasses the capabilities necessary to insert humans into Earth orbit and return them safely to Earth, employing a post-Space Shuttle flight system. The flight elements of the Exploration Spiral 1 Crew Transportation System are the Crew Exploration Vehicle and CEV Launch Vehicle. Robotic Precursor Missions that are scheduled to launch prior to the Earth orbit demonstration of the Spiral 1 CTS are considered Exploration Spiral 1 missions.

Exploration Spiral 2 (Lunar Global Access for Human Exploration) Encompasses the capabilities necessary to execute human lunar exploration anywhere on the surface of the moon. Lunar global access exploration missions will be 4-7 days in duration on the lunar surface, and do not require pre-deployed surface systems (e.g., Habitation Module or Surface Power). Robotic Precursor Missions scheduled to launch after the Spiral 1 CTS flight demonstration, and prior to the first Spiral 3 Lunar mission are considered Exploration Spiral 2 missions.

Exploration Spiral 3 (Lunar Base and Mars Testbed) Encompasses the capabilities necessary to execute a long-duration human lunar exploration campaign. This campaign requires development of extensive surface systems (e.g., habitation and surface power system). Robotic Precursor Missions that are scheduled to launch after the last Spiral 2 extended- duration lunar mission, and prior to the initial Exploration Spiral 4 mission are considered Exploration Spiral 3 missions.

Exploration Spiral 4 (Crew Transportation System Mars Flyby) Encompasses the capabilities to conduct a Mars flyby mission using elements of the Human-Mars Crew Transportation System. Upon completion of successful Mars flyby(s), Exploration Spiral 5 will commence. Robotic Precursor Missions scheduled to launch after the first CTS Mars Flyby mission, and prior to the first Human-Martian surface mission are considered Spiral 4 missions.

Exploration Spiral 5 (Human Mars Surface Campaign) Spiral 5 encompasses the capabilities necessary to execute human Mars exploration missions. Robotic Precursor Missions scheduled to launch after the final Mars flyby mission, and prior to the start of Exploration Spiral 6 (content currently undefined) are considered Spiral 5 missions.

Ground Operations Phase Begins with the start of mission planning. Representative activities include: mission planning, training, receipt of government hardware/software, acceptance, test, checkout, repair, inspection, assembly, integration, servicing and countdown activities. Also includes ground contingency, emergency, abort and turnaround operations. Phase ends with vehicle liftoff.

Ground Support System This system provides all common ground-based capabilities (e.g., mission control, launch-site processing) needed to execute Exploration missions. Facilities and capabilities that are unique to a single Exploration System, such as the CTS, will be included as part of the system it supports.

Guidance and Control The process of directing the movements of a space vehicle, including selection of a flight path and making changes in attitude and speed.

Inclination The angle between the plane of an orbit and the Earth's equator for all geocentric orbits.

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In-Space Support System (IS³) This system will encompass capabilities provided by infrastructure elements (e.g., a communication satellite or network) that are placed in orbital, or lunar/planetary locations. These capabilities are exclusive of those provided by elements of the DSS.

Independent Technical Authority (ITA) A responsibility owned by the NASA Chief Engineer, which is then delegated through the issuance of warrants. A warrant holder is designated as compliance officer over an identified set of engineering and technical requirements or standards.

Integrated Logistics Support (ILS) Is an approach that enables disciplined, unified and iterative management of support considerations into system and equipment design. ILS includes development of support requirements that are related to readiness objectives, to design, and to each other. Requirements in turn drive acquisition of required support; ILS is then employed during the operational phase.

Initial Lunar Phasing Orbit Used in Spiral 2 and 3 to define the orbit where the CEV will assume delta V requirements for a potential docking in lunar orbit. Defined by the following parameters: Altitude: 100 km x 500 km +/- (**TBD-6**) km (**TBR-34**); Maximum inclination error with respect to the Lunar Reference Orbit; 0.5 degrees (**TBR-28**).

Launch Availability The likelihood that a given launch will be achieved without a scrub once the mission timeline (first element launch for a multiple launch mission) or the launch countdown call to stations (for a mission scenario involving a single launch) has commenced. Launch availability is composed of four elements: system availability, launch probability, launch site weather constraints and abort weather constraints. Launch Availability can be expressed as: $P(LA) = P(SA) \times P(LP) \times P(LW) \times P(AW)$

Where:

P(LA) = Launch Availability (overall probability of achieving a launch)

P(SA) = System Availability (probability of hardware being acceptable for launch)

P(LP) = Launch Probability (probability that the vehicle limits are not violated by upper level winds or other natural environment phenomena)

P(LW) = Launch Weather (probability that other launch site weather constraints are not violated)

P(AW) = Abort Weather (probability that abort weather constraints are not violated)

Launch Azimuth The initial heading of a powered vehicle at launch.

Launch Opportunity The period of time during which the relative position of the launch site and orbital plane permit a launch vehicle to perform the ascent function.

Long-Duration (Lunar Mission) Human missions to the lunar surface that require pre-deployed Surface Systems. This capability is a requirement in Exploration Spiral 3, and encompasses surface stays from 42 days (threshold) up to 98 days (objective) **(TBR-70)**.

Low Earth Orbit (LEO) A stable orbit around the Earth with a minimum orbital altitude of 170 km.

Lunar Architecture Focused Trade Study Ongoing engineering analysis (led by NASA JSC) of lunar architecture and mission design options, in support of Exploration architecture decision-making. Results of this study are captured in document ESMD-RQ-0005, "Lunar Architecture Focused Trade

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Study Final Results".

Lunar Ascent Orbit Used in Exploration Spirals 2 and 3 to define the orbit that the LSAM must achieve when launching from the lunar surface. Defined by the following parameters: Altitude: 100 km +/- (**TBD-8**) km; Inclination angle (wedge angle) with respect to Lunar Reference Orbit: Maximum of 10 degrees (**TBR-71**).

Lunar Reference Orbit Used in Exploration Spirals 2 and 3 to define the lunar orbit for rendezvous and docking of Exploration elements. Defined by the following parameters: Altitude: 100 km +/- (**TBD-8**) km; Inclination: Optimized for the mission.

Lunar Surface Access Module (LSAM) Provides crew transport to the lunar surface from the Lunar Reference Orbit and return from the surface to the Lunar Ascent Orbit.

Mating The act of mechanically connecting together two major elements of a system. Mating can be performed in space, through docking or berthing, or on the ground through docking, berthing, or other interfaces.

Mission Capable Refers to the status of an Exploration flight element or mated elements, which have sufficient consumables to fully execute its intended mission from its current location in space.

Mission Opportunity Refers to the Earth departure window to conduct a mission to another planetary destination such as the Moon or Mars. Typically constrained by orbital mechanics and the design of the Exploration System. If assembly of elements in Earth orbit is required, then "Mission Opportunity" refers to the departure window from Earth orbit based on the capability of the Exploration System.

Mission Phase Definitions Used as the basis for functional flow and decomposition of reference Spiral 3 human exploration mission. The Mission Phases identified were Ground Operations, Earth to Orbit, Earth Orbit Operations, Earth Orbit to Destination Vicinity, Destination Vicinity Operations (A), Destination Vicinity to Surface, Surface Operations, Destination Surface to Destination Vicinity, Destination Vicinity Operations (B), Destination Vicinity to Earth, Earth Reentry, and Recovery (see associated definitions).

Net Habitable Volume The functional pressurized volume left available to the crew after accounting for the loss of volume due to deployed equipment, stowage, trash, and any other items which decrease functional volume. The gravity environment corresponding to the habitable volume must be specified.

Objective Used in requirements language to define the desired capability above the threshold that should be evaluated for feasibility and affordability. Capabilities above the objective are not expected to be pursued or analyzed.

Payload The onboard scientific and exploration utilization (i.e. ISRU) equipment carried by a given spacecraft, generally quantified in terms of mass and volume. Also expressed as the entire mass delivered by a launch vehicle, to orbit.

Polar Regions of the Moon Defined as the area between 80-90 degrees (**TBR-74**) lunar latitude (threshold), with an objective of 70-90 degrees (**TBR-76**).

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Probabilistic Risk Assessment A set of methodologies employed to determine quantitative probability a given end state or states (e.g., Loss of Mission, Loss of Crew) will occur. Probabilistic Risk Assessment results can be used to develop or validate Fault Trees and Failure Modes analysis. They also can be used as a tool for making design and logistics decisions.

Proximity Operations Orbital flight operations conducted during any period when two or more vehicles are operating near enough to affect one another (e.g., prior to or post rendezvous and docking).

Recovery Phase Begins with completion of Earth surface landing and includes recovery forces operations, vehicle safing, vehicle configuration for recovery, crew egress, crew return to post-mission facilities. Ends with vehicle recovery to post-mission facilities for refurbishment or disposal.

Remotely Commanded Operations The capability to operate a vehicle, system, or subsystem from an external location (e.g., mission control). Remotely commanded operations do not require the presence of an onboard crew.

Robotic Precursor Mission A robotic spacecraft mission that supports The Vision by achieving scientific objectives and/or through preparing for future human exploration activities.

Robotic Precursor System Robotic spacecraft that are developed to execute missions that prepare for and support future human exploration, and to accomplish science objectives.

Safety-Critical Software Software is safety-critical if it meets at least one of the following criteria:

- 1. Resides in a safety-critical system (as determined by a hazard analysis AND at least one of the following:
 - a. Causes or contributes to a hazard.
 - b. Provides control or mitigation for hazards.
 - c. Controls safety-critical functions.
 - d. Processes safety-critical commands or data.
 - e. Detects and reports, or takes corrective action, if system reaches hazardous state.
 - f. Mitigates damage if a hazard occurs.
 - g. Resides on the same system (processor) as safety-critical software.
- 2. Processes data or analyzes trends that lead directly to safety decisions (e.g., determining when to turn power off to a wind tunnel to prevent system destruction.)
- 3. Provides full or partial verification or validation of safety-critical systems, including hardware or software subsystems.

Segment Used in the CTS requirements development process to express the identity of two or more elements mated together and operating jointly in a given set of mission phases. Segments defined this way facilitate functional decomposition of capabilities throughout the reference Exploration Spiral 3 mission. For example, the In-Space Transportation Segment is comprised of the CEV and an Earth Departure Stage, and comprises the CTS from the Earth Orbit Operations Mission Phase until CEV-EDS separation during the Destination Vicinity Operations Mission Phase. Other segments were defined as the CEV Launch Segment (CEV and CLV operating through separation in Earth orbit), the Destination Transportation Segment (CEV and LSAM operating in the lunar vicinity), and the Earth Return Segment (CEV only, upon separation from LSAM Ascent Stage).

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Spiral Development Process A phased system of system development process that allows increasing capabilities to be achieved in support of long range objectives. While work can be accomplished concurrently against the objectives associated with multiple spirals, the completion of all objectives for a given spiral is considered necessary to enable achievement of the succeeding spiral. See associated definitions for Exploration Spirals.

Strategy to Task to Technology Process (STTP) Use of engineering analysis to validate architectural and mission design approaches, and identify technology investment needs.

Surface Operations Phase Starts at the completion of landing on the destination surface, including propulsion system shutdown and safing. Representative mission activities include: science operations, system and operational testing, surface EVA, assembly and maintenance, vehicle checkout, and preparation for ascent. Phase ends at initiation of ascent from the destination surface (i.e., T0).

System of Systems A set or arrangement of interdependent systems that are related or connected to provide a given capability. The loss of any portion of the System of Systems will degrade the performance or capabilities of the whole. The systems contained in the Exploration System of Systems (ESS) are: the Crew Transportation System, Cargo Delivery System, In-Space Support System, Destination Surface System, Robotic Precursor System, and Ground Support System. Requirements, constraints, and guidelines that apply to all human and robotic exploration systems are levied against the Exploration System of Systems, and may apply against any or all Exploration Spirals, as specified. The term "System of Systems" is sometimes expressed synonymously as "Super-system".

Threshold Used in requirements language to define the minimum capability necessary to satisfy the requirement.

Transfer Volume The passageway between two connected element that can contain crew.

Wedge Angle The angle change that must be accomplished (i.e., delta-V capability) to exit an Earth Reference Orbit and achieve a desired Lunar Reference Orbit (see Lunar Reference Orbit).

4.3 Requirements Taxonomy

The following table is provided as a key to understanding the taxonomy used for requirement Unique ID numbers (i.e., the Unique ID number is shown at the beginning of each requirement statement).

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System/Segment	Req. Number	Spiral
ESS (Exploration System of Systems Technical)	0001 -	A = Spiral 1
EPR (Exploration Programmatic Requirements)	9999	B = Spiral 2
EPG (Exploration Programmatic Guidelines)		C = Spiral 3
CTS (Crew Transportation System)		D = Spiral 4
, ,		E = Spiral 5
CVS (CEV Launch Segment)		F = Spirals 1&2
CEV (Crew Exploration Vehicle)		G = Spirals 2&3
CLV (CLV Launch Vehicle)		H = Spirals 1,2,3